DISCLAIMER

INCREASED OIL PRODUCTION AND RESERVES UTILIZING SECONDARY/TERTIARY RECOVERY TECHNIQUES ON SMALL RESERVOIRS IN THE PARADOX BASIN, UTAH

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Utah Geological Survey (UGS), Salt Lake City, Utah 84114-6100

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Objectives

The primary objective of this project is to enhance domestic petroleum production by demonstration and technology transfer of an advanced oil recovery technology in the Paradox basin, southeastern Utah. If this project can demonstrate technical and economic feasibility, the technique can be applied to about 100 additional small fields in the Paradox basin alone, and result in increased recovery of 150 to 200 million barrels of oil. This project is designed to characterize five shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation and choose the best candidate for a pilot demonstration project for either a waterflood or carbon dioxide-(CO_2-) flood project. The field demonstration, monitoring of field performance, and associated validation activities will take place in the Paradox basin within the Navajo Nation. The results of this project will be transferred to industry and other researchers through a petroleum extension service, creation of digital databases for distribution, technical workshops and seminars, field trips, technical presentations at national and regional professional meetings, and publication in newsletters and various technical or trade journals.

Summary of Technical Progress

Two activities continued this quarter as part of the geological and reservoir characterization of productive carbonate buildups in the Paradox basin: (1) diagenetic characterization of project field reservoirs, and (2) technology transfer.

Diagenetic Characterization of Project Field Reservoirs

Geological characterization on a local scale focused on reservoir heterogeneity, quality, and lateral continuity as well as possible compartmentalization within each of the five project fields (Fig. 1). The diagenetic fabrics and porosity types found in the various hydrocarbon-bearing rocks of each field can be an indicator of reservoir flow capacity, storage capacity, and potential for water-and/or CO_2 flooding. In order to determine the diagenetic histories of the various Desert Creek reservoirs, thin sections of 50 representative samples were selected for petrographic description and analysis.

All depositional, diagenetic, and porosity information were placed into the context of the production history to date of each field in order to construct a detailed overview for each enhanced recovery candidate. Of special interest was the determination of the most effective pore systems for oil drainage versus storage.

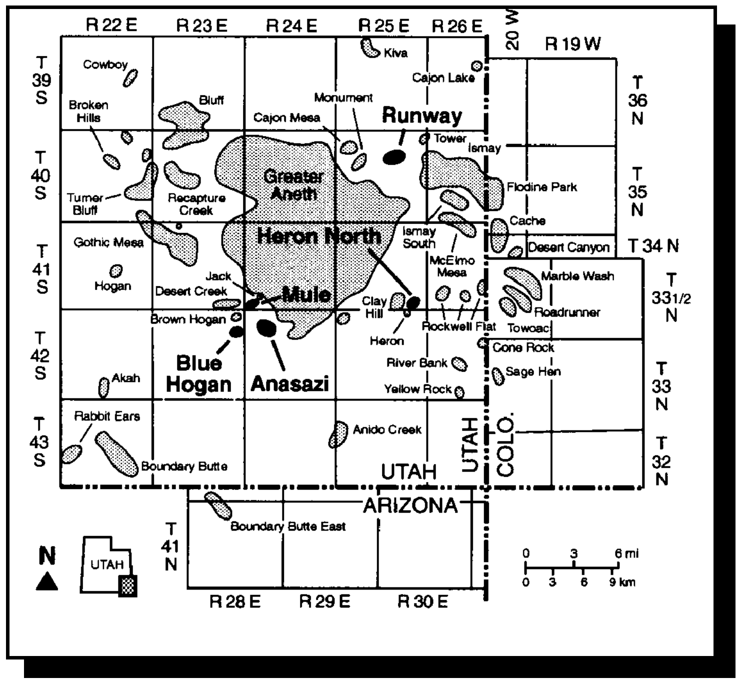


Fig. 1. Location of project fields (dark shaded areas with names in bold type) in the southwestern Paradox basin on the Navajo Nation, San Juan Co., Utah.

Diagenetic Environments

Most shallow-shelf/shelf margin carbonate buildups or mounds had topographic relief which was subaerially exposed when sea level dropped (Fig. 2). This produced four major diagenetic environments: (1) fresh water (meteoric) vadose zone (above the water table, generally at or near sea level), (2) meteoric phreatic zone (below the water table), (3) marine phreatic zone, and (4) mixing zone.[1] The "iceberg" principle (the Ghyben-Herzberg theory), which states that for every foot the water table rises above sea level there may be 20 ft (6.1 m) of fresh water below the water table can generally be applied to both carbonate mound and island buildups.[2] Neomorphism, leaching/dissolution, and fresh water cementation (dog tooth, stubby, and small equant calcite) take place within the vadose and meteoric phreatic zones.

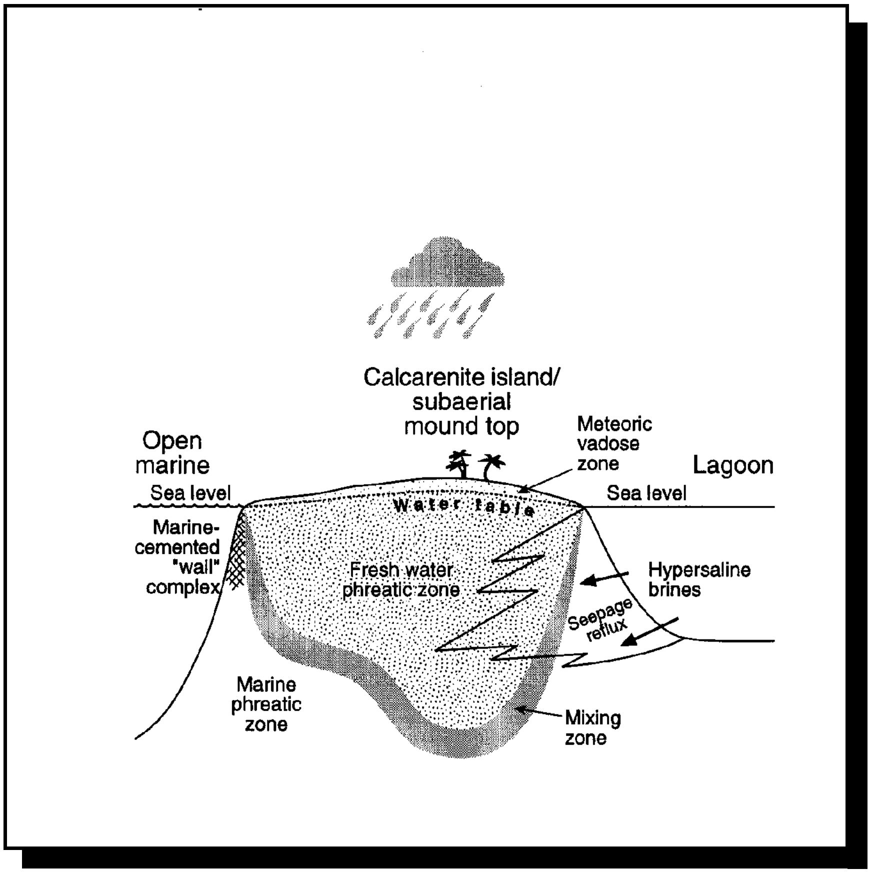


Fig. 2. Diagrammatic cross section showing distribution of the diagenetic environments of subaerially exposed shallow-shelf/shelf margin carbonate buildups or mounds. Modified from Longman, reprinted with permission.[1]

Both the meteoric phreatic zone and marine phreatic zone are dynamic, changing with sea level fluctuations. These phreatic zones are separated by a mixing zone (fresh and sea water) which also changes with sea level fluctuation. Early dolomitization takes place in the mixing zone. Most carbonate buildups (fields) have a mixing zone as well as a fresh water overprint.

That portion of the carbonate buildup facing the open-marine environment is generally a steep-wall complex where early-marine cements (such as fibrous isopachous, botryoidal, and radiaxial cements) are deposited from invading sea water pumping through the system. The other side of the mound typically borders a hypersaline lagoon. The dense brine from the lagoon can seep into the phreatic zone, a process termed seepage reflux, forming a wedge-shaped zone of low-temperature dolomite deposition; both early replacement dolomite and dolomite cement.

Anasazi Field

The producing mud-poor to mud-rich, mound-core interval (5,646 to 5,670 ft [1,721-1,728 m]) in the Anasazi field is a limestone with a packstone to bafflestone fabric.[3,4] Framework grains consist of phylloid algal plates (dominating), brachiopods, bryozoans, pelloids, ostracods, and forams. Early marine cement is present and a limited amount of fresh water influence is indicated either from the vadose zone or outside the fresh water (phreatic) zone resulting in some fresh water cement. There is some bitumen plugging and anhydrite replacement. The diagenetic events occurred in the following order: (1) fibrous isopachous early marine cementation, (2) some stubby to equant to dog tooth spar cementation in shelter pores or molds, (3) saddle dolomite cementation, (4) anhydrite replacement, and (5) bitumen plugging. The basic pore types are primary shelter pores and secondary moldic pores. The reservoir has excellent flow capacity because much of the primary porosity and permeability was preserved.

The producing supra-mound interval (5,582 to 5,630 ft [1,701-1,716 m]) is a dolomite with a packstone to grainstone fabric. Framework grains consist of coated skeletal grains and pelloids. A significant fresh water influence is indicated by the presence of degrading neomorphism and leaching. Dolomitization occurred in the mixing zone or from seepage reflux. There is some anhydrite plugging. The diagenetic events occurred in the following order: (1) degrading neomorphism, (2) dissolution, (3) early replacement dolomitization, (4) saddle dolomite cementation, and (5) anhydrite plugging. The basic pore types are primary interparticle pores and secondary moldic pores. The reservoir has an excellent storage flow capacity and is a candidate for CO_2 flooding because the overall diagenetic events increased porosity.

Blue Hogan Field

The producing mud-rich, mound-core interval (5,412 to 5,446 ft [1,650-1,600 m]) in the Blue Hogan field is a limestone with a bafflestone fabric.[4,5] Framework grains consist of phylloid algal plates with dolomite sphericals replacing utricules (original microstructures of phylloid algae). The buildup represents a high-energy reef wall which resulted in pervasive early marine cementation throughout what originally had been rock with high porosity (Fig. 3). There is also some anhydrite replacement. The typical diagenetic events occurred in the following order: (1) first generation micrite and fibrous isopachous early marine cementation, (2) second generation botryoidal early marine cementation, (3) third generation radiaxial early marine cementation, (4) post-burial replacement rhombic dolomite cementation, (5) equant calcite cementation, and (6) anhydrite replacement. The basic pore types are primary shelter pores now filled with cement; and secondary moldic and channel pores. The reservoir has a moderate flow capacity because the pervasive amounts of cement.

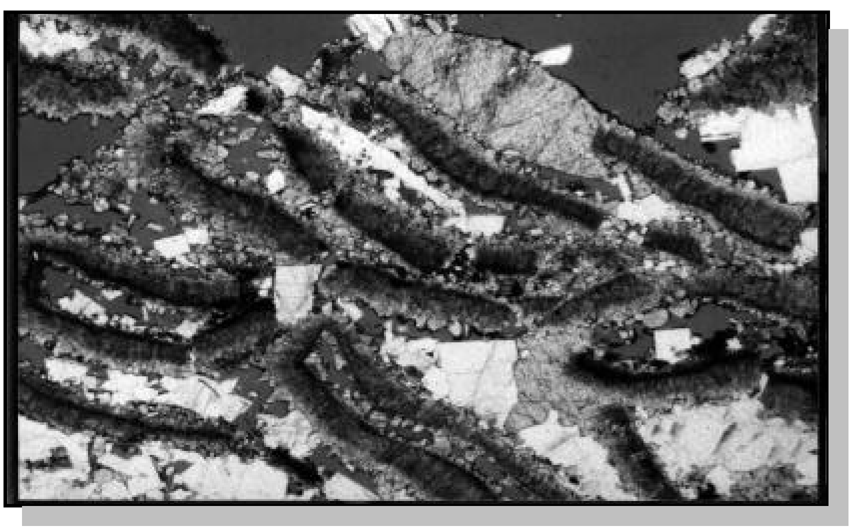


Fig. 3. Thin section (18.5X, plane light), from the 5,512.4 ft in the Blue Hogan No. 1-J-1 well, of a limestone bafflestone with phylloid plates broken by early mechanical compaction, some preservation of shelter pores, early marine and syntaxial cementation, and anhydrite replacement.

Heron North Field

The producing platform-margin calcarenite interval (5,584 to 5,606 ft [1,702-1,709 m]) is a dolomite with a grainstone fabric (Fig. 4).[4,6] Framework grains consist mainly of pelloids, surficial ooids, and coated skeletal grains deposited in a high-energy, beach depositional environment. Classic fresh water diagenesis or near-surface meteoric overprinting suggests early burial associated with an island. Dolomitization most likely resulted from seepage reflux. There is both anhydrite and bitumen plugging. The diagenetic events occurred in the following order: (1) degrading neomorphism, (2) dissolution by fresh water, (3) early first generation replacement dolomitization (fine grain dolomite), (4) second generation of dolomitization (coarse grain), (5) anhydrite replacement and plugging, and (6) bitumen plugging. The basic pore types are secondary moldic, intercrystalline, micro-intercrystalline, and channel pores. The reservoir has an excellent storage flow capacity and is a candidate for CO_2 flooding due to enhanced porosity from dolomitization.

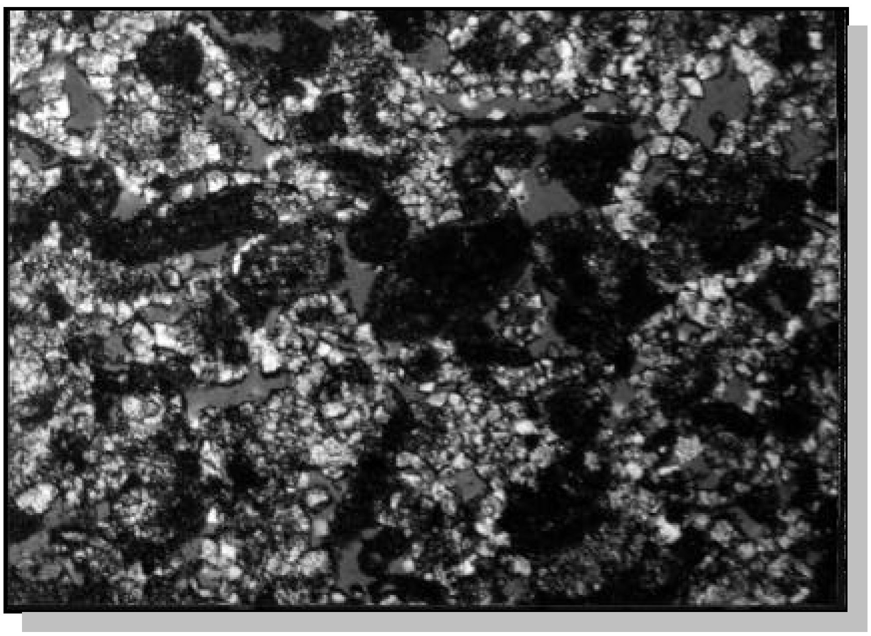


Fig. 4. Thin section (50X, plane light), from the 5,569.2 ft in the North Heron No. 35-C well, of a dolomitic, oolite- and pelloid-bearing grainstone with early and late generations of dolomite, and excellent intercrystalline porosity.

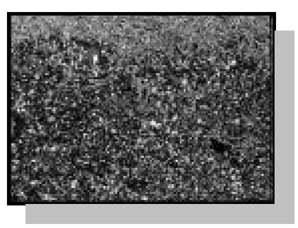
Mule Field

The producing mud-poor, mound-core interval (5,728 to 5,753 ft [1,746-1,753 m]) is a limestone with a bafflestone fabric.[4,7] Framework grains consist of phylloid algal plates and bryozoans. Some early marine cement and minor fresh water cements are present. There is both silica and anhydrite replacement. The typical diagenetic events occurred in the following order: (1) minor fibrous isopachous early marine cementation, (2) minor dissolution and dog tooth cementation by fresh water, (3) post-burial equant calcite cementation, (4) late saddle dolomite cementation in molds replacing calcite cement, (5) some silicification, and (6) anhydrite replacement. The basic pore types are primary shelter and interparticle pores; and secondary moldic pores. The reservoir has an excellent flow capacity because primary porosity has been preserved.

The producing supra-mound interval (5,660 to 5,680 ft [1,725-1,731 m]) is a dolomite with a skeletal packstone to grainstone fabric. Framework grains consist of bryozoans and phylloid algal plates. A heavy fresh water influence is indicated by the presence of degrading neomorphism and leaching, often seen as a solution front. Dolomitization occurred in the mixing zone or from seepage reflux. There is some anhydrite cement and bitumen plugging. The diagenetic events occurred in the following order: (1) degrading neomorphism, (2) dissolution, (3) dog tooth spar cementation, (4) early replacement dolomitization, (5) plugging of pores by late dolomite, calcite, and anhydrite cements, and (6) bitumen plugging. The basic pore types are secondary channel, moldic, intercrystalline, and micro-intercrystalline pores. The reservoir has a good storage flow capacity from the secondary porosity development and is a candidate for CO_2 flooding.

Runway Field

The bryozoan buildup interval (5,940 to 5,946 ft [1,810-1,815 m]) is a limestone with a high energy grainstone fabric.[4,8] Framework grains consist of bryozoans, crinoids, phylloid algal plates, bivalves, forams, and clasts produced by brecciation. Some early marine cement and mixing zone dolomite (two generations) are present as well as anhydrite replacement (Figs. 5 and 6). The typical diagenetic events occurred in the following order: (1) minor early marine cementation, (2) dog tooth and equant calcite cementation, (3) syntaxial cementation, (4) mechanical brecciation producing clasts, (5) first generation (early) dolomitization - medium-sized crystals, (6) second generation (late) dolomitization - very coarse crystals, (7) later saddle dolomite cementation, and (8) anhydrite replacement. The basic pore types are primary interparticle pores; and secondary intercrystalline and moldic pores. The reservoir has good flow capacity based on the amount of porosity and permeability development.



The producing supra-mound interval (5,890 to 5,904 ft [1,795-1,800 m]) is a dolomite (100%) with a grainstone fabric. Framework grains consist of ooids, pelloids, grain aggregates, ostracods, and some phylloid algal plates deposited in a high energy, shallow water to beach environment. A heavy fresh water influence is indicated by the presence of degrading neomorphism and patchy dissolution. Dolomitization occurred in the mixing zone or from seepage reflux. The result is little cementation and a heterogeneous porosity development. The diagenetic events occurred in the following order: (1) degrading neomorphism and dissolution, (2) first generation (early) dolomitization (finely crystalline), and (3) second generation (late) dolomitization (coarsely crystalline). The basic pore types are secondary moldic, intercrystalline, micro-intercrystalline, and channel pores. The reservoir has good storage flow capacity and is a candidate for CO_2 flooding.

Technology Transfer

The Utah Geological Survey (UGS) released the January 1998 issue of *Petroleum News* featuring the Paradox basin project. The project home page on the UGS Internet web site (http://www.ugs.state.ut.us/paradox.htm) was updated with the latest quarterly technical report and project publications list.

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FIGURE CAPTIONS

Fig. 5. Thin section (18.5X, plane light), from the 6,120.2 ft in the Runway No. 10-C-5A well, of a dolomitic wackestone with ghosts of ostracods and crinoids, degrading neomorphism and leaching, two generations of dolomitization, intercrystalline porosity, and bitumen plugging.

Fig. 6. Thin section (18.5X, plane light), from the 6,127.4 ft in the Runway No. 10-C-5A well, of a limestone wackestone with phylloid algal plates, crinoids, pelloids in mud brecciated by mechanical compaction; some leaching; dog tooth spar, syntaxial, and saddle dolomite cement.